

Dual-Wavelength Spectral Purity Filter for EUV Collector Mirrors

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PTB Berlin

Washington, D.C., October 27, 2014

Outline

- Introduction
- Spectral Purity Filter for main pulse CO₂ laser wavelength: 10.6 μm
- Spectral Purity Filter for pre pulse YAG laser wavelength: 1064 μm
- Dual-wavelength Spectral Purity Filter
- Summary and acknowledgement

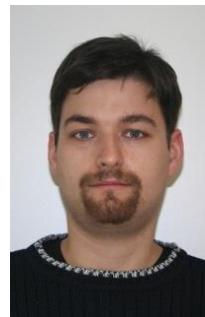
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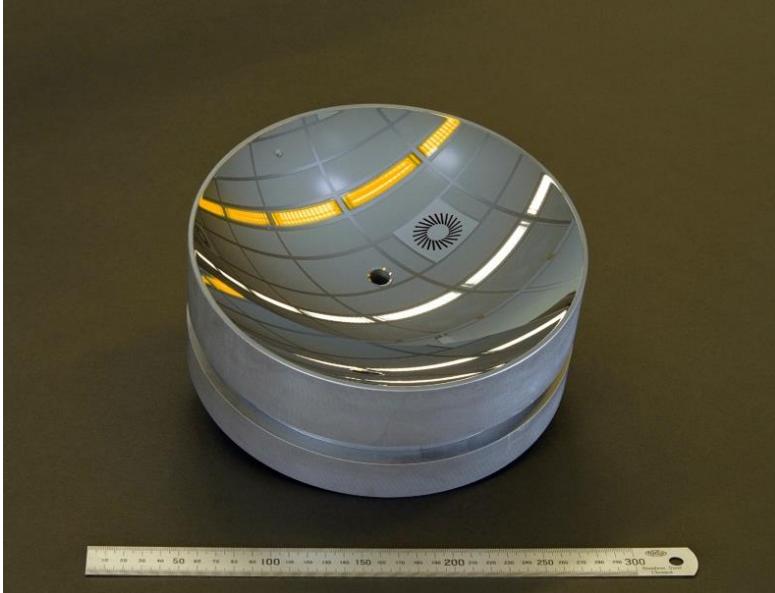
optiX fab introduction

- Mission: Fabrication of customized EUV optics and optical components for EUV lithography @ 13.5 nm and beyond, synchrotron and FEL beamlines, metrology, R&D applications, etc.
- Foundation: December 17, 2012, fully operational: August 1, 2013
- Address: optiX fab GmbH
Hans-Knöll-Str. 6
D - 07745 Jena
- Email: info@optixfab.com
- Production: Delivery of > 3000 EUV multilayer mirrors since Aug 1, 2013

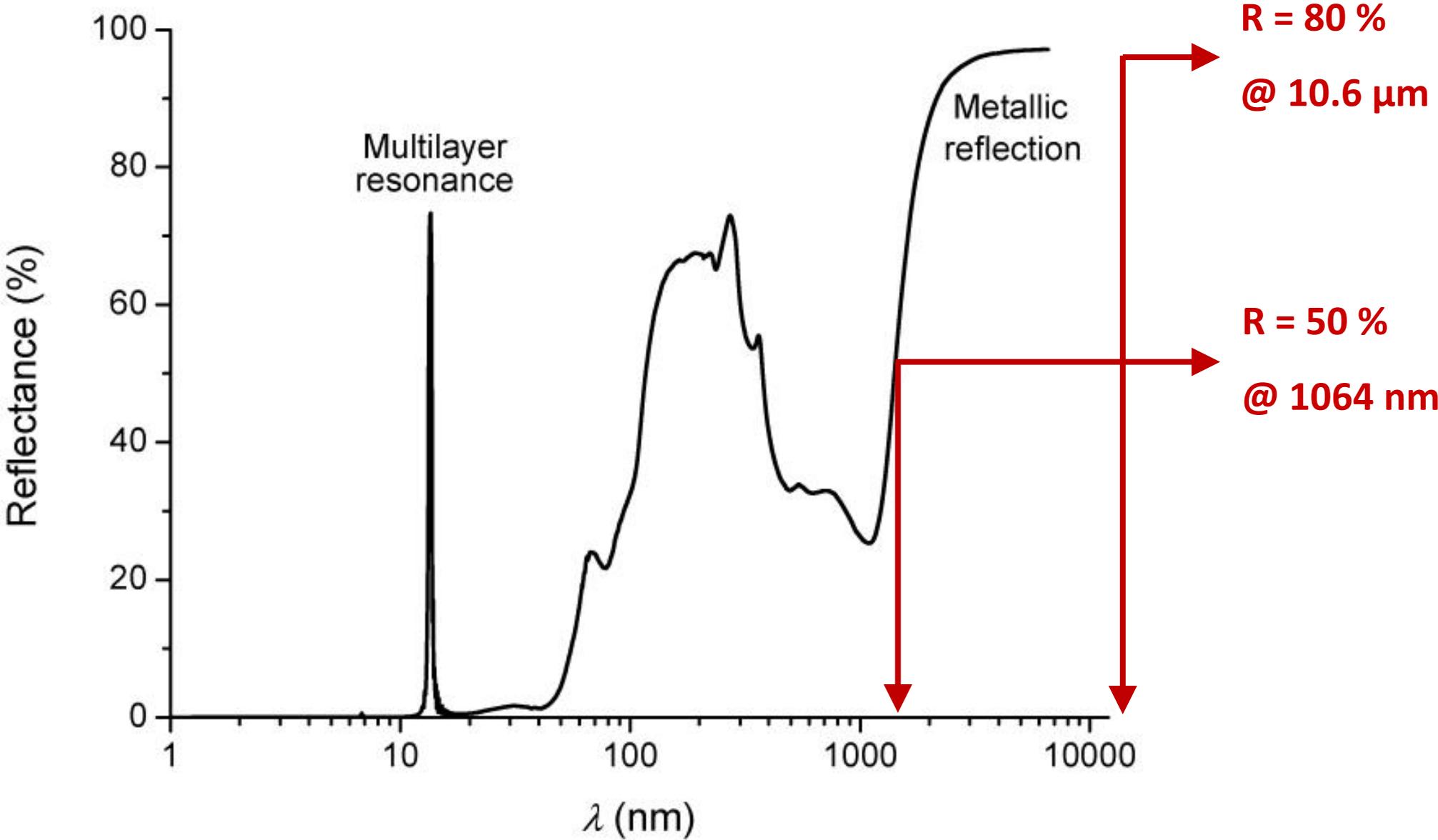
- Team:



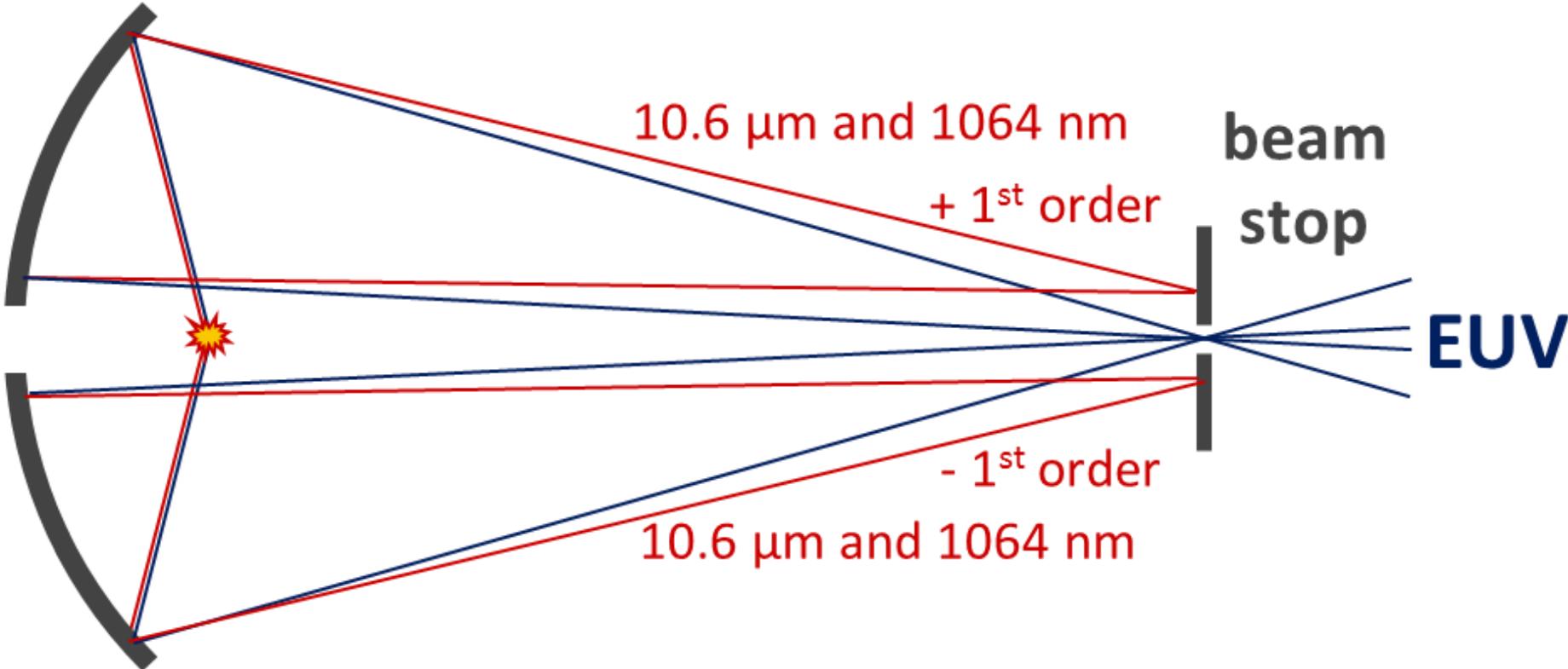
Multilayer coated collector optics for LPP sources



Theoretical reflectance of Mo/Si multilayer for normal incidence



EUV LPP collector with dual-wavelength spectral purity filter



**EUV collector
with integrated
binary phase grating**

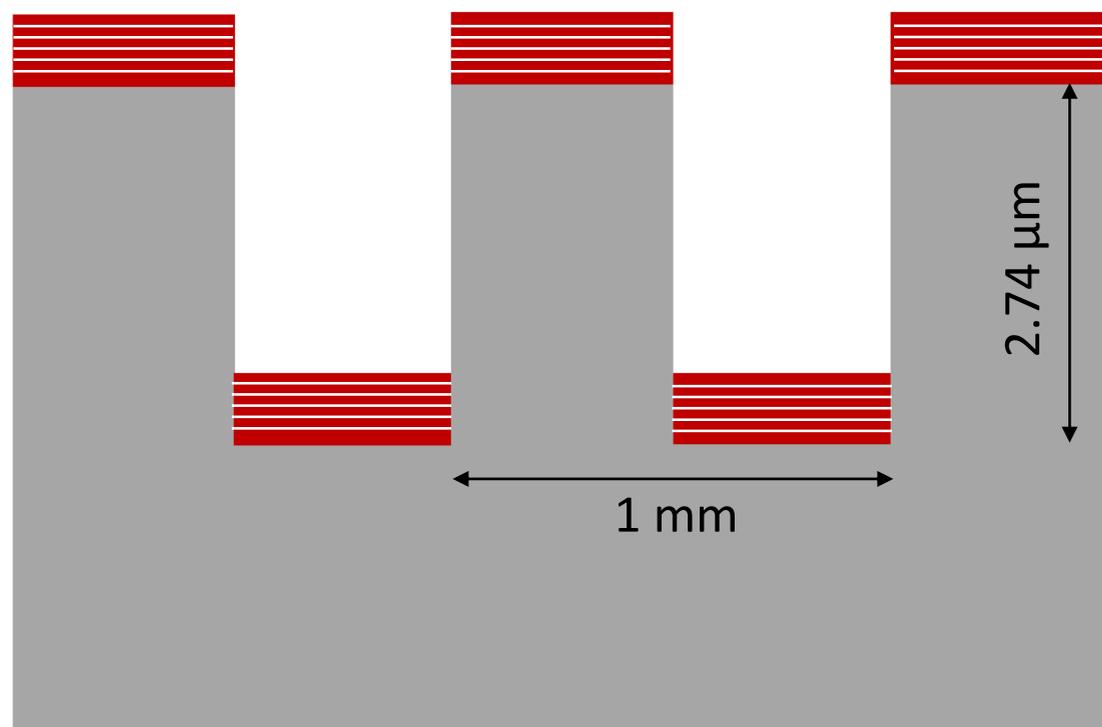
Dual-wavelength spectral purity filter – proof of principle

- Realization of binary phase gratings on 6 inch Si wafers
- Optimization of grating and coating for AOI = 15 degrees
- Characterization of grating structure by WLI
- Characterization of grating roughness by AFM
- Characterization of optical properties:
 - EUV reflectance at 13.5 nm and
 - IR suppression at 10.6 μm and 1064 nm

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Spectral Purity Filter for CO₂ laser wavelength: 10.6 μm



Grating period: 1 mm

Grating height: 2.74 μm

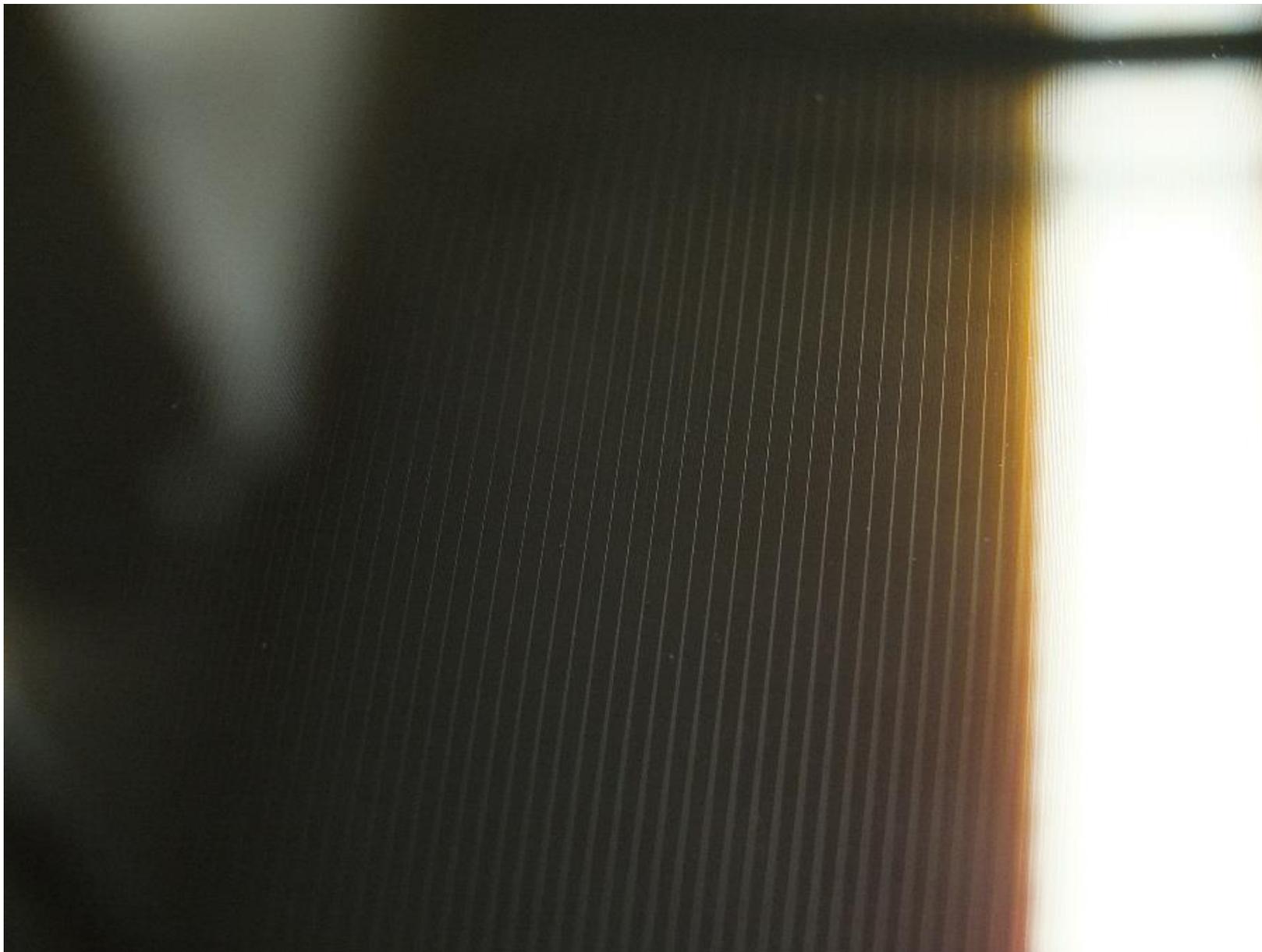


Mo/Si multilayer (N = 60)

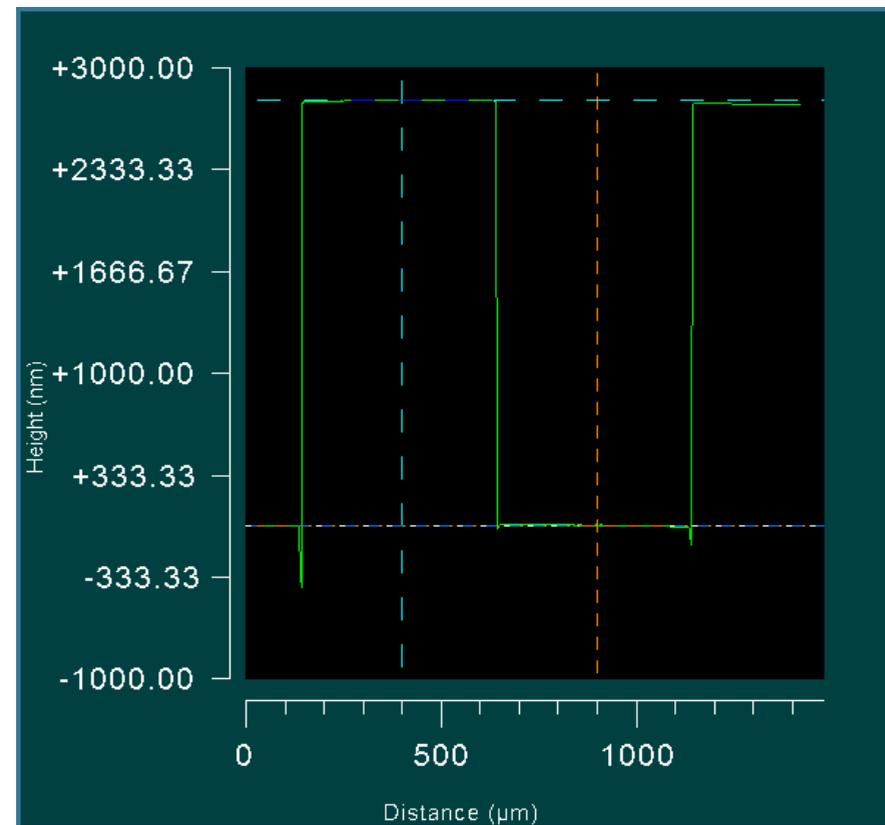
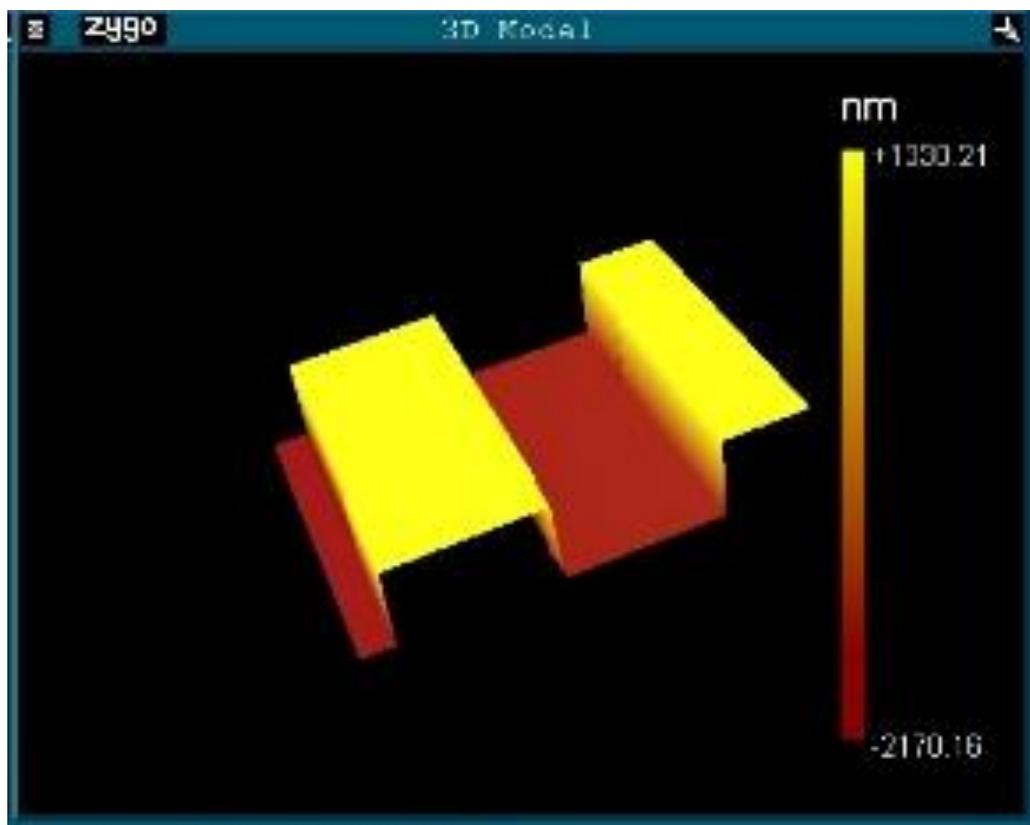


Substrate

Photographs of grating structure

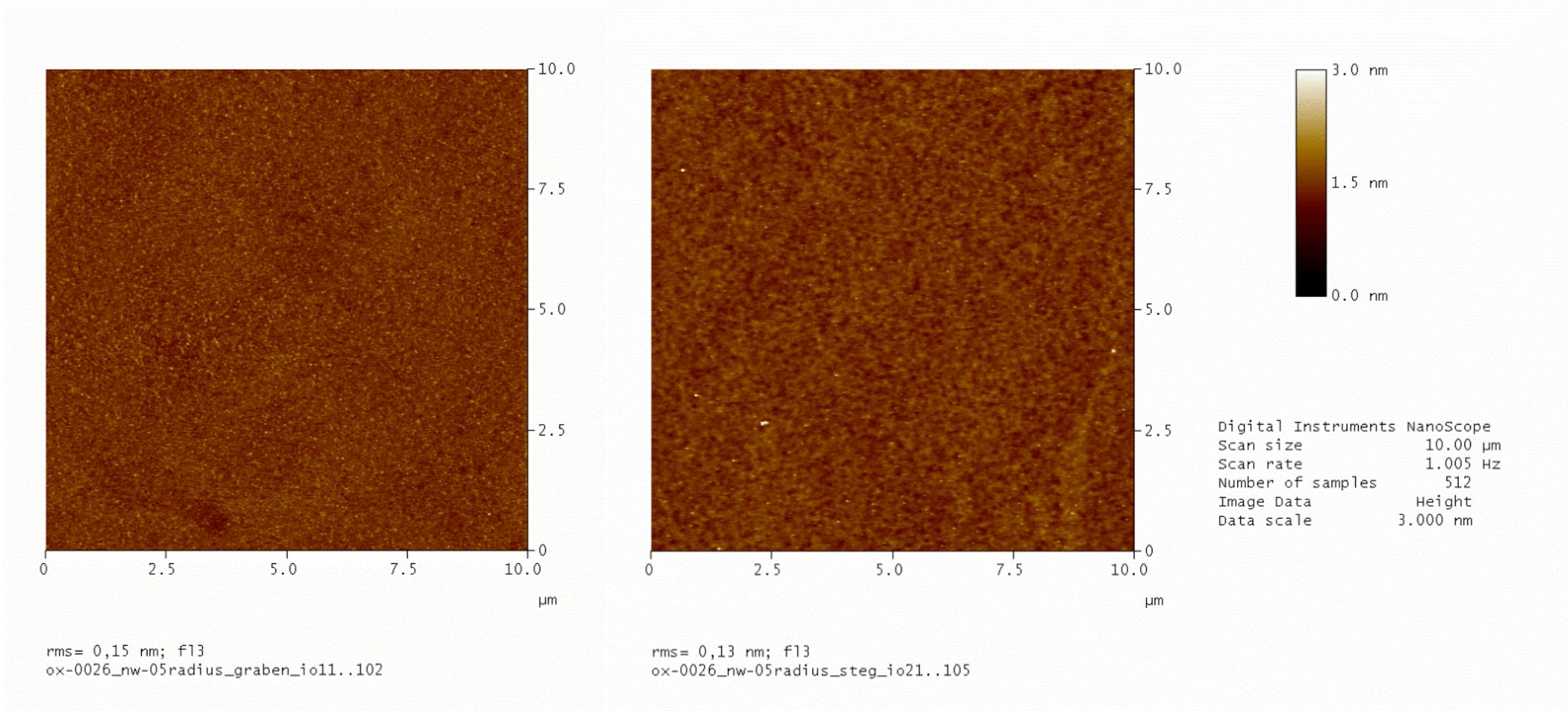


White light interferometry of grating structure



Grating for:	10.6 μm
Bar width	499 μm
Groove width	501 μm
Groove depth	2740 nm

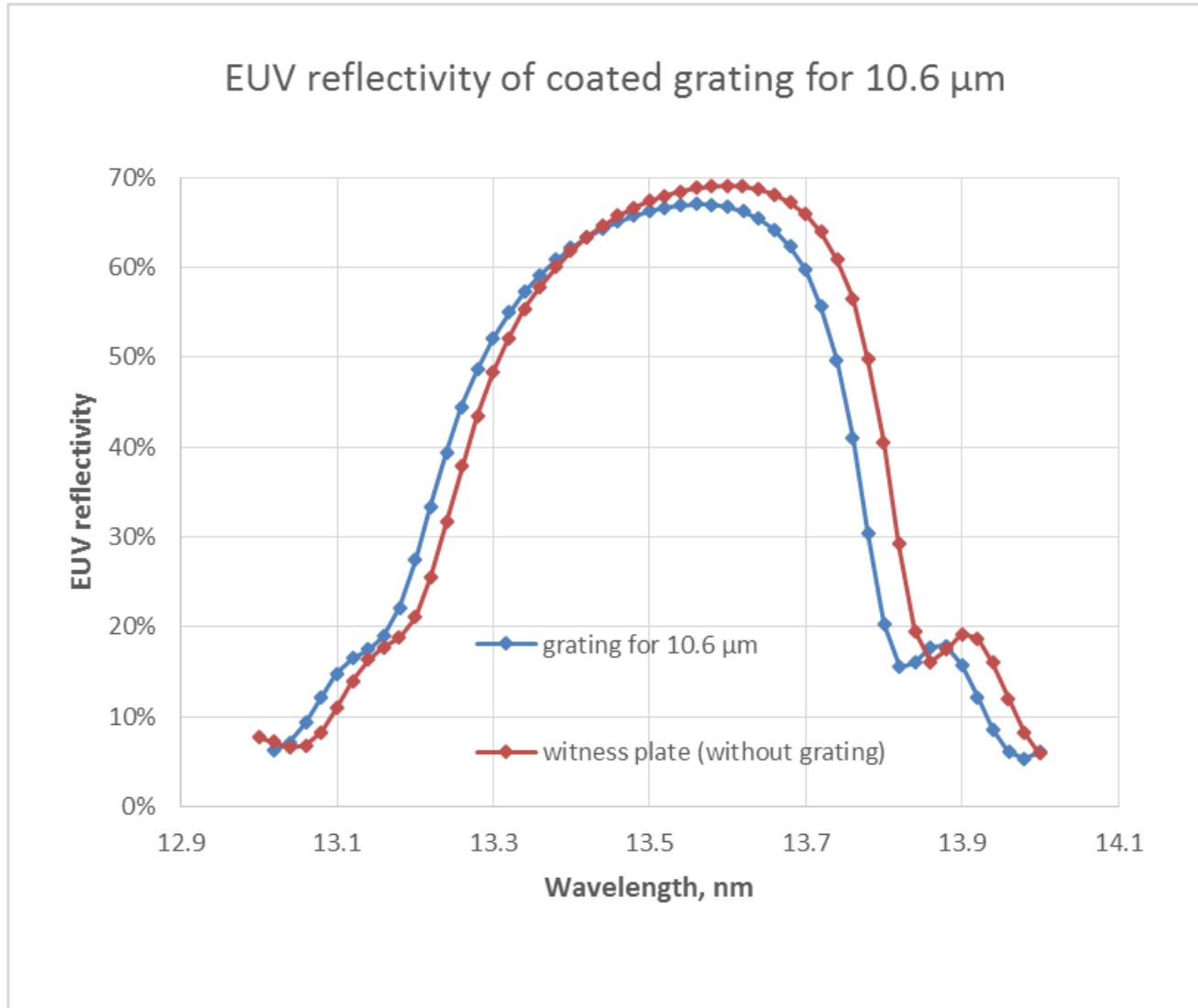
Atomic Force Microscopy of grating bar and groove



rms roughness on grating groove:
 $\sigma_{\text{RMS}} = 0.15 \text{ nm}$

rms roughness on grating bar:
 $\sigma_{\text{RMS}} = 0.15 \text{ nm}$

EUV reflectance measurement @ PTB Berlin



EUVR on grating structure

$R = 67.0\%$

$\lambda_{\text{center}} = 13.49 \text{ nm}$

EUVR on witness sample

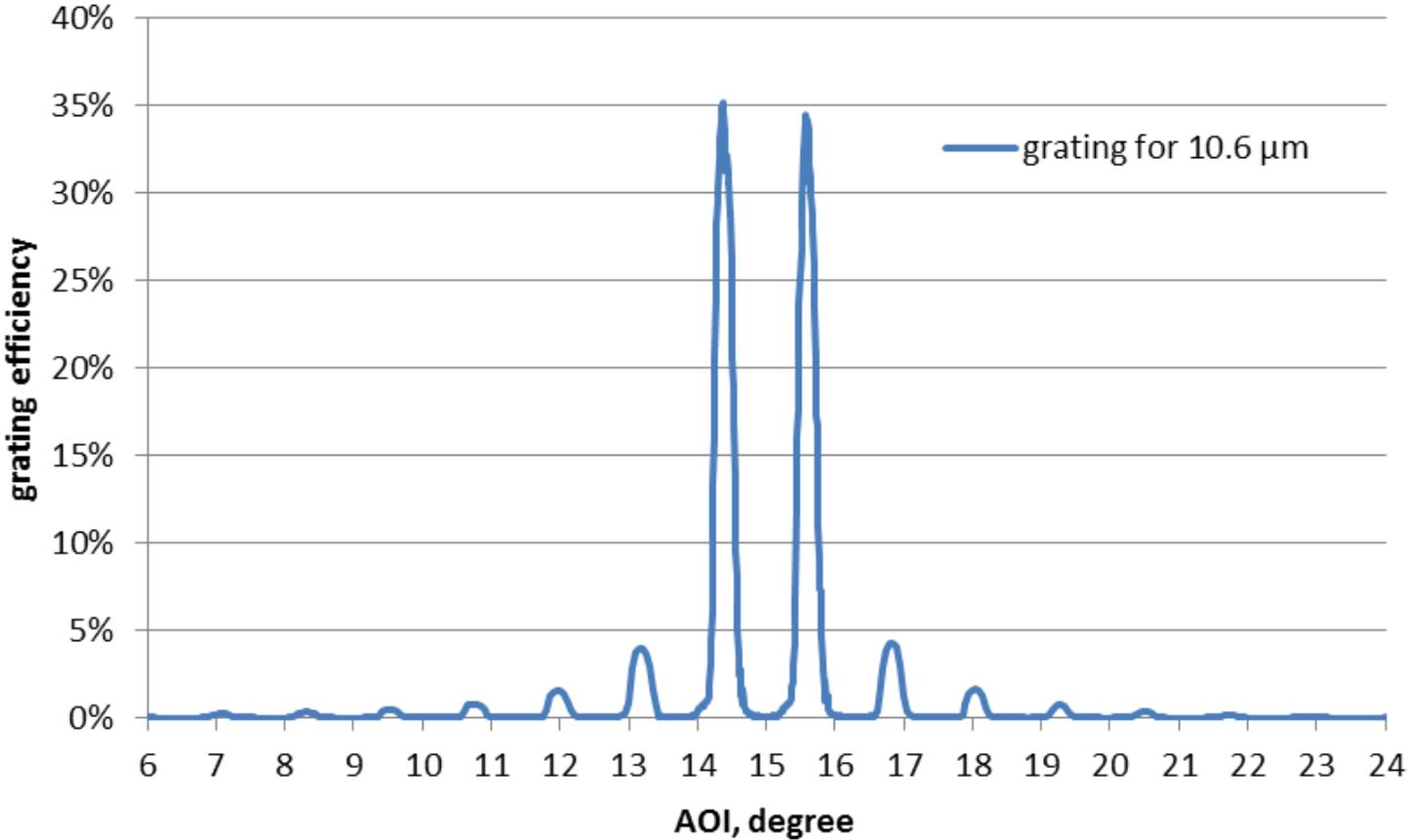
$R = 69.1\%$

$\lambda_{\text{center}} = 13.53 \text{ nm}$



**2.1 % (abs.) EUVR loss
due to grating structure**

Grating efficiency @ 10.6 μm



Grating efficiency @ 10.6 μm

0th order:	0.06 %
- 1st order:	34.5 %
+ 1st order:	35.2 %

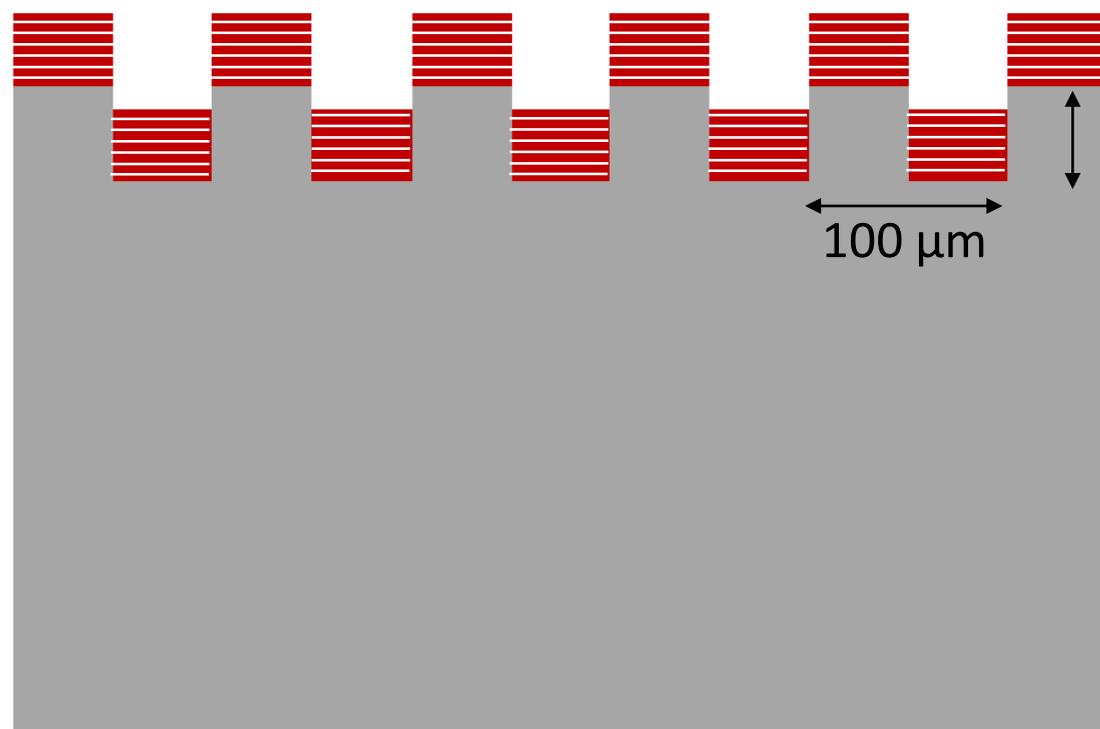


IR suppression factor:
1500

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Spectral Purity Filter for YAG laser wavelength: 1064 nm



Grating period: 100 μm

Grating height: 275 nm

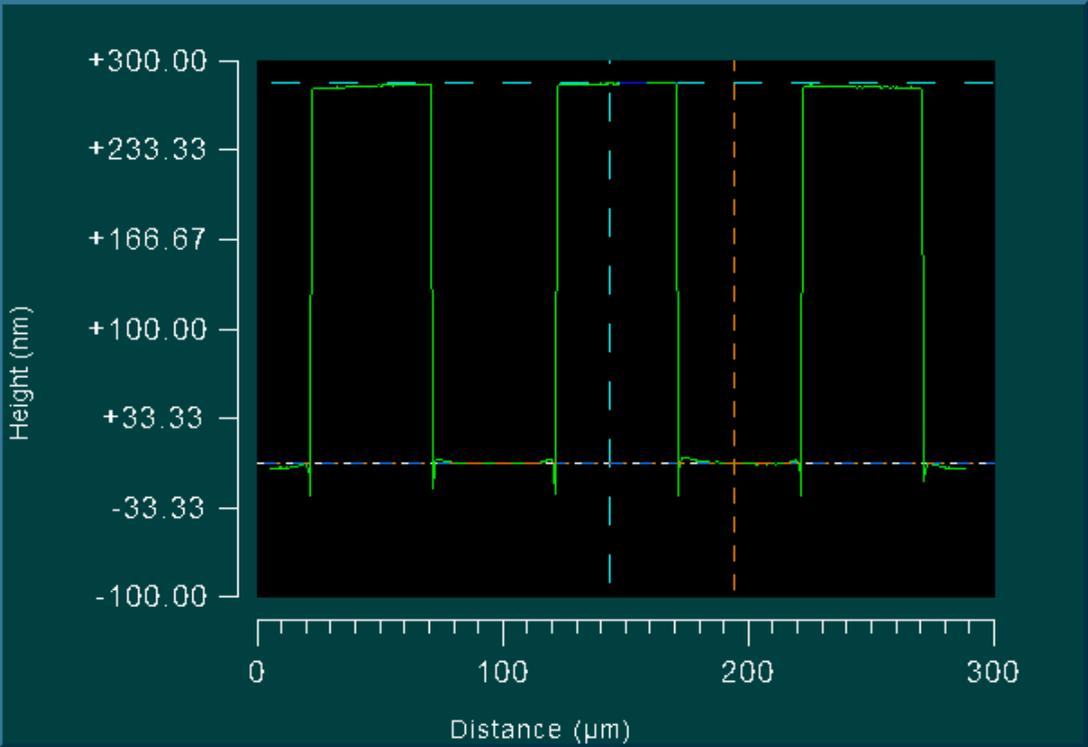
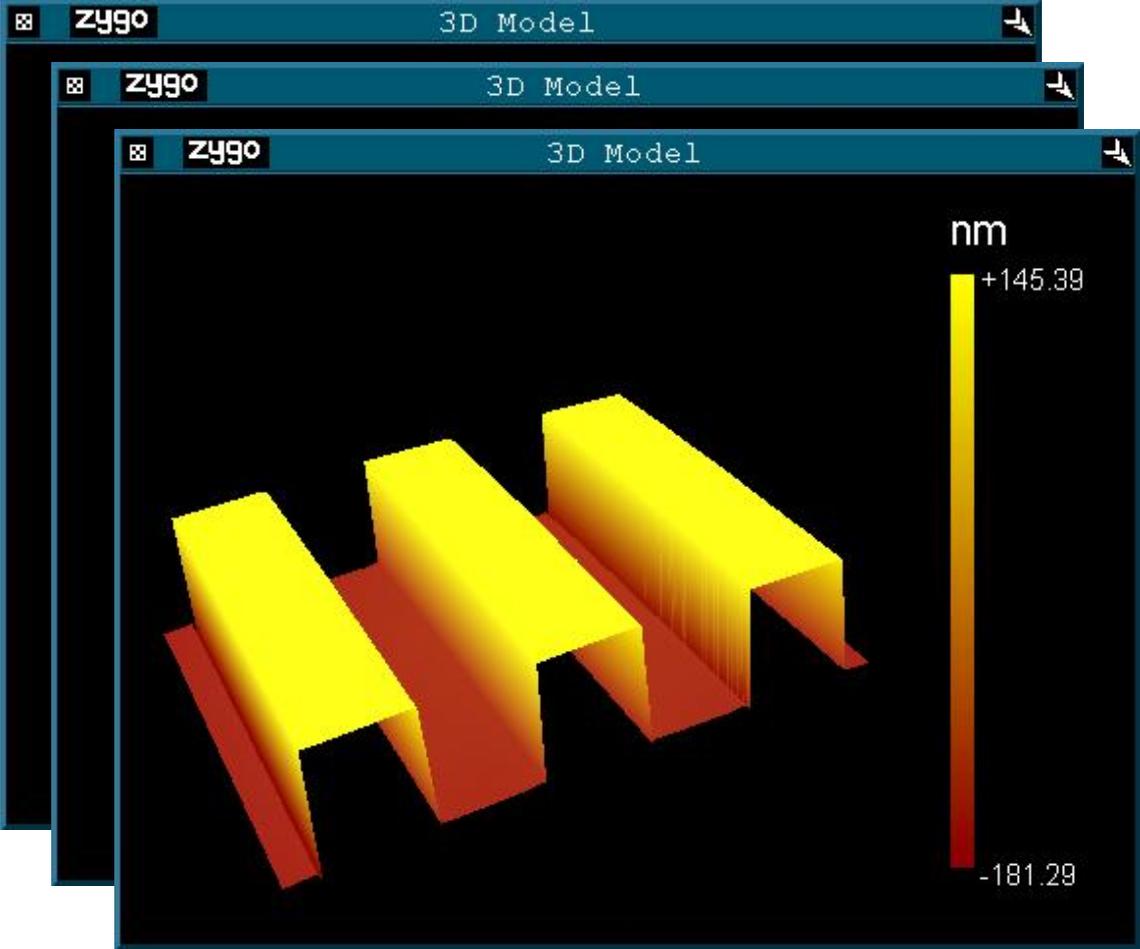


Mo/Si multilayer (N = 60)



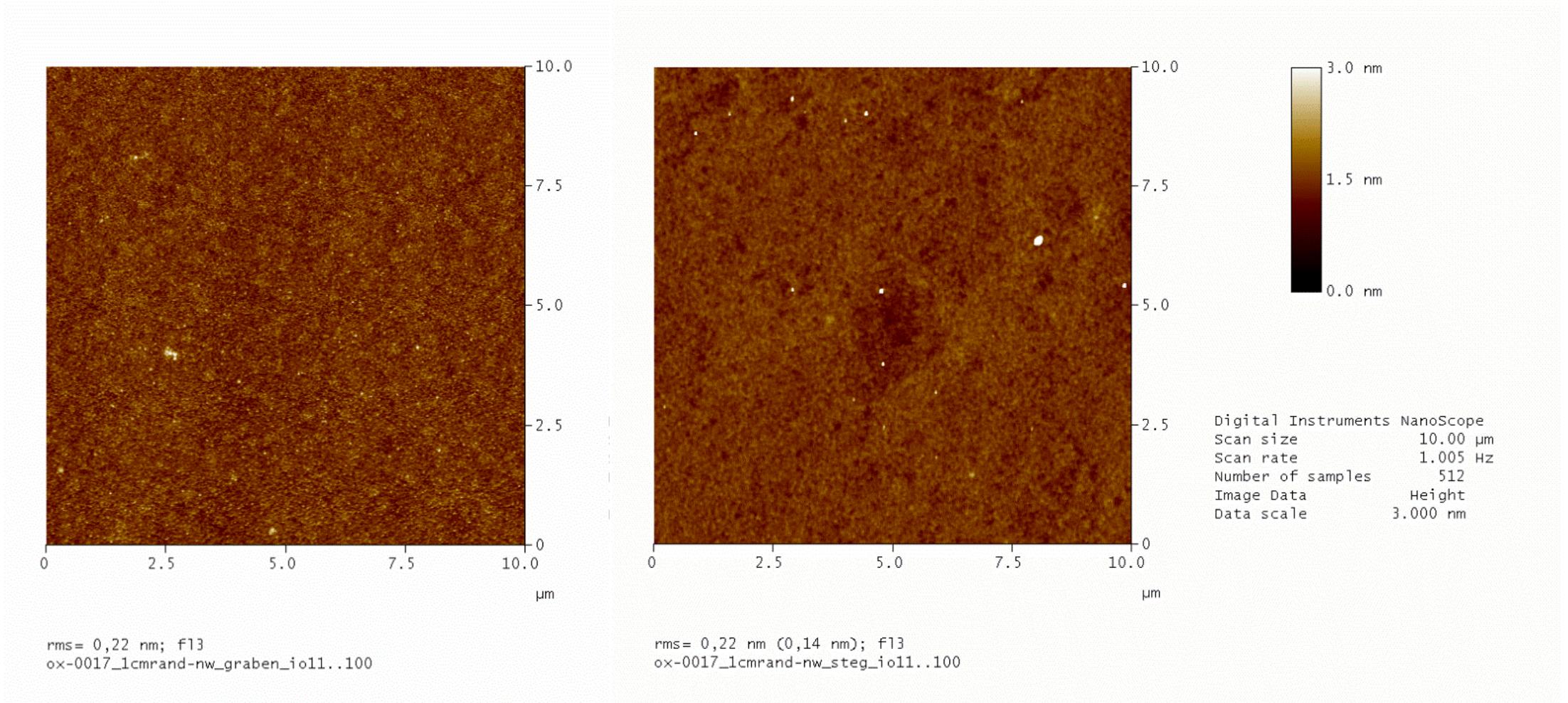
Substrate

White light interferometry of grating structure



Grating for:	1064 nm
Bar width	49.6 μm
Groove width	50.1 μm
Groove depth	284 nm

Atomic Force Microscopy of grating bar and groove



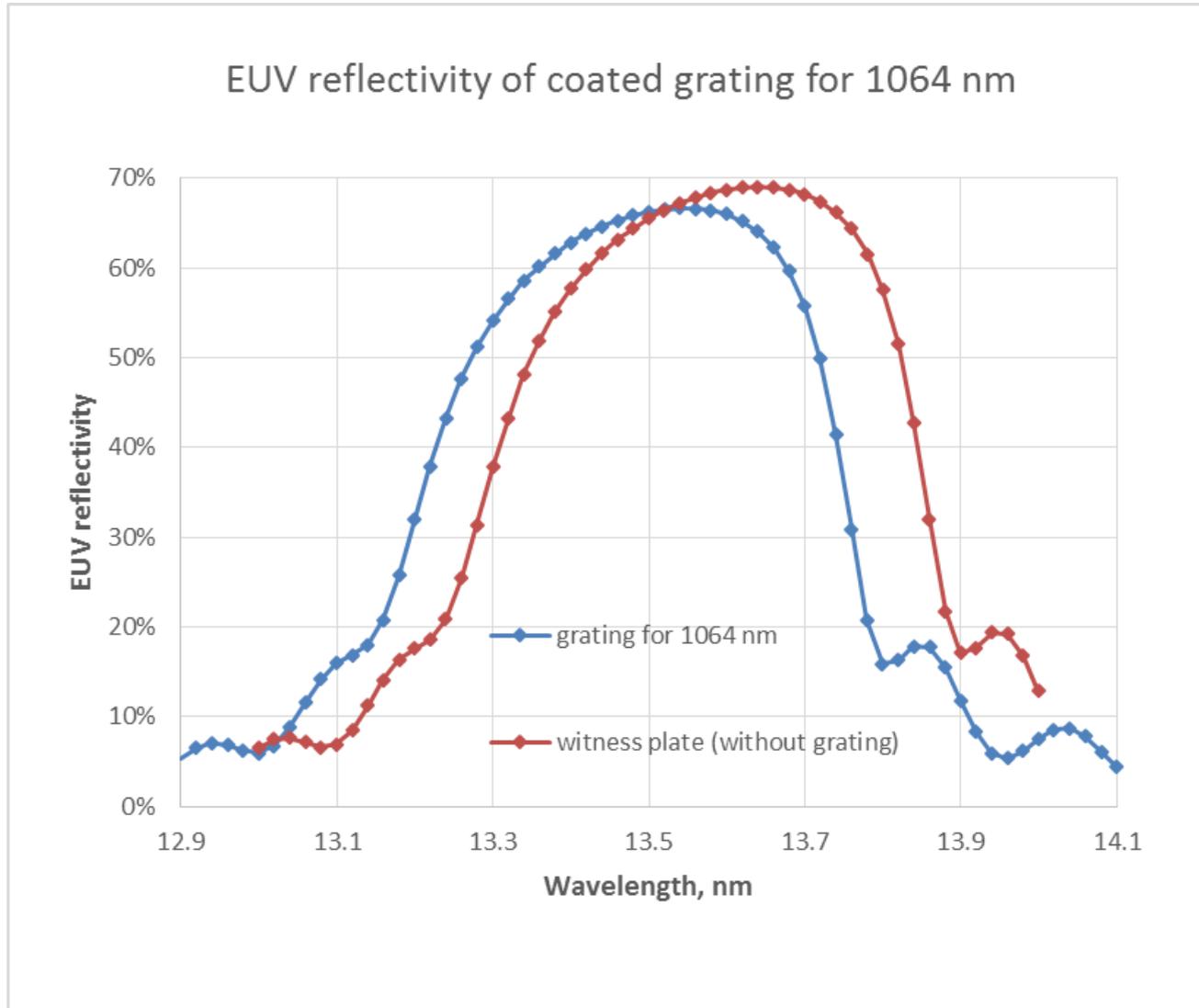
rms roughness on grating groove:

$$\sigma_{\text{RMS}} = 0.22 \text{ nm}$$

rms roughness on grating bar:

$$\sigma_{\text{RMS}} = 0.14 \text{ nm}$$

EUV reflectance measurement @ PTB Berlin



EUVR on grating structure

R = 66.6 %

$\lambda_{\text{center}} = 13.48 \text{ nm}$

EUVR on witness sample

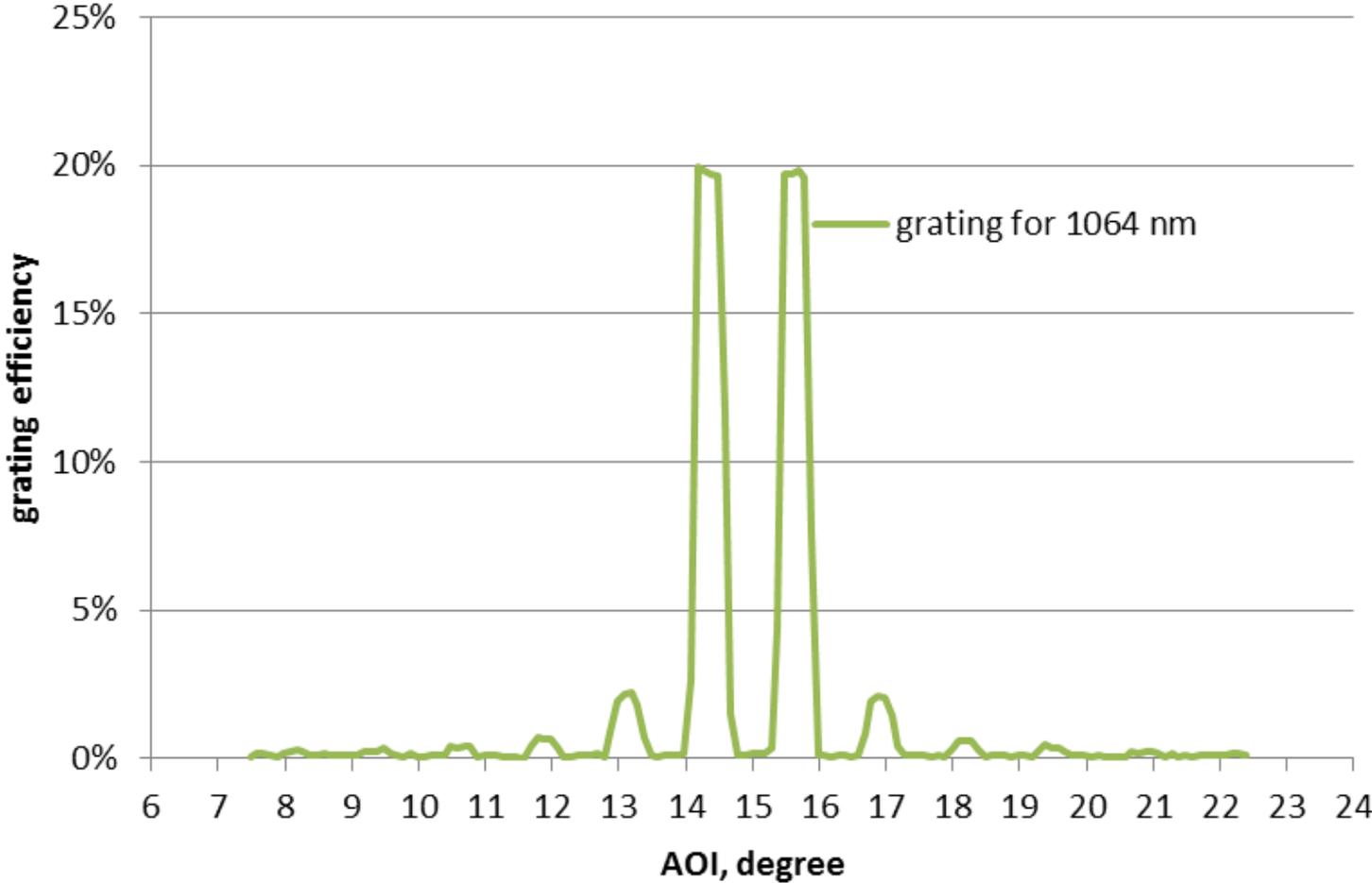
R = 69.0 %

$\lambda_{\text{center}} = 13.52 \text{ nm}$



**2.4 % (abs.) EUVR loss
due to grating structure**

Grating efficiency @ 1064 nm



Grating efficiency @ 1064 nm

- 0th order: 0.17 %
- 1st order: 19.9 %
- + 1st order: 19.9 %

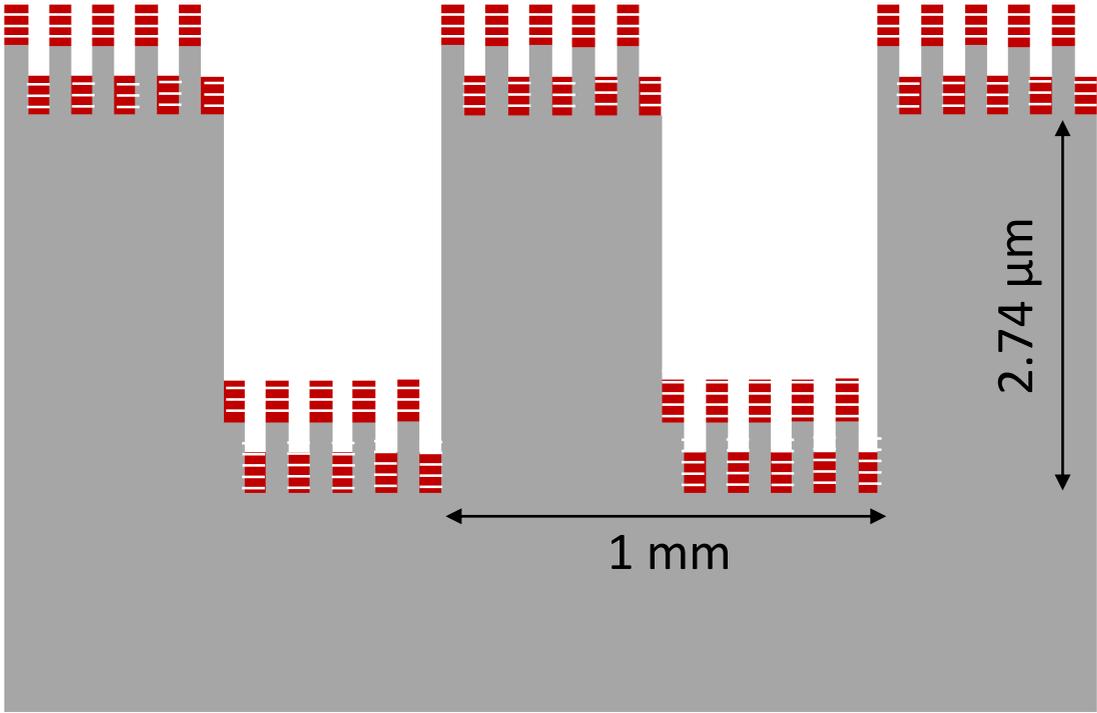


IR suppression factor:
600

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- **Dual-wavelength Spectral Purity Filter**
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Dual-wavelength Spectral Purity Filter

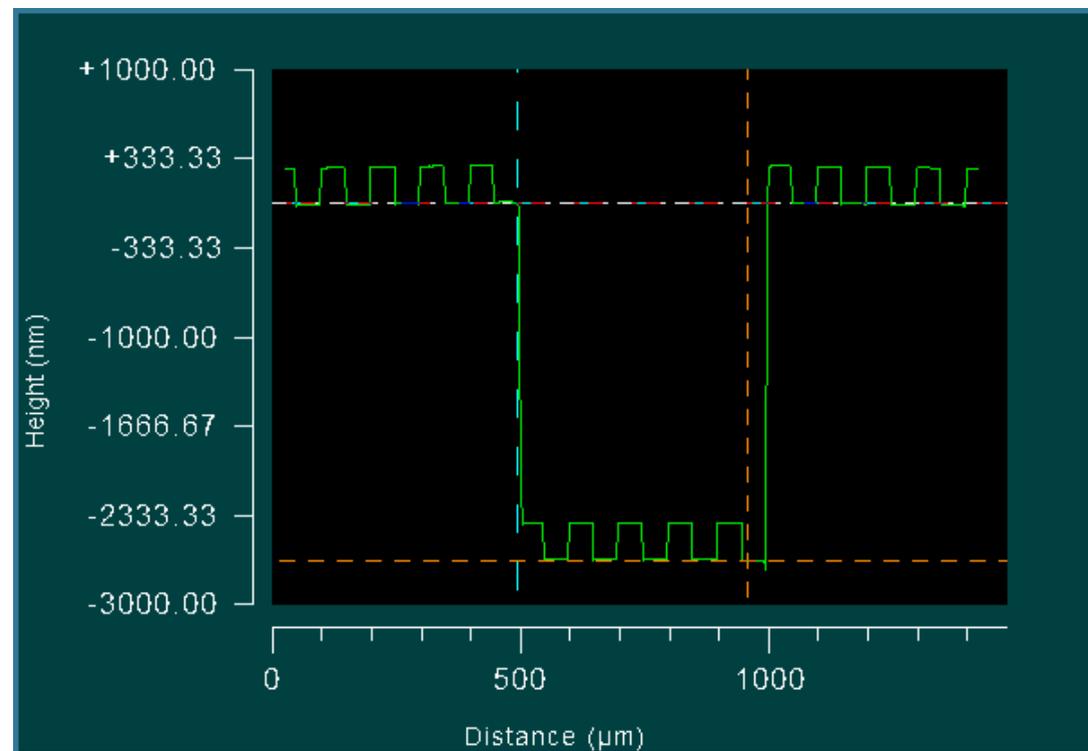
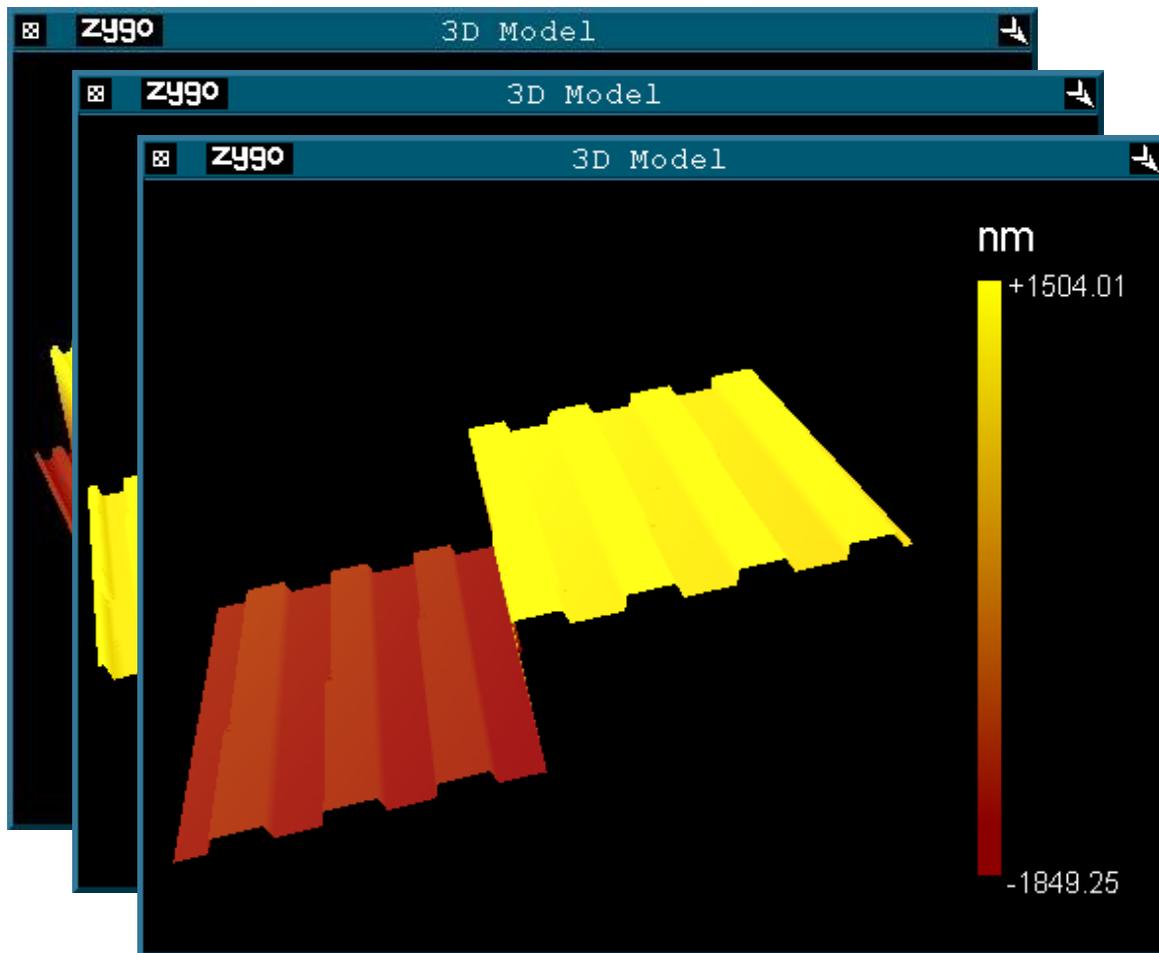


CO₂ laser grating:
Grating period: 1 mm
Grating height: 2.74 nm

YAG laser grating:
Grating period: 100 μm
Grating height: 275 nm

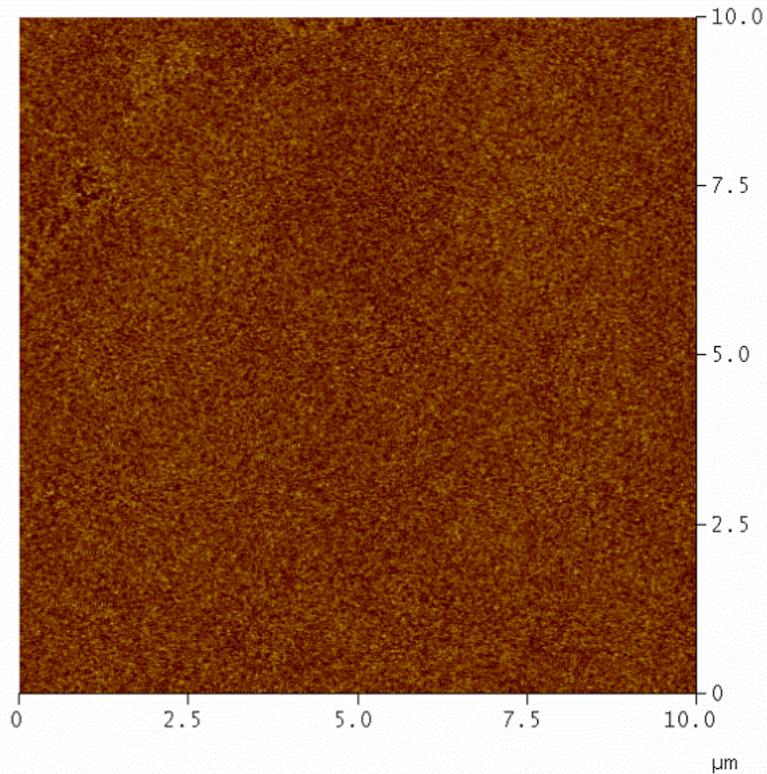
-  Mo/Si multilayer (N = 60)
-  Substrate

White light interferometry of grating structure

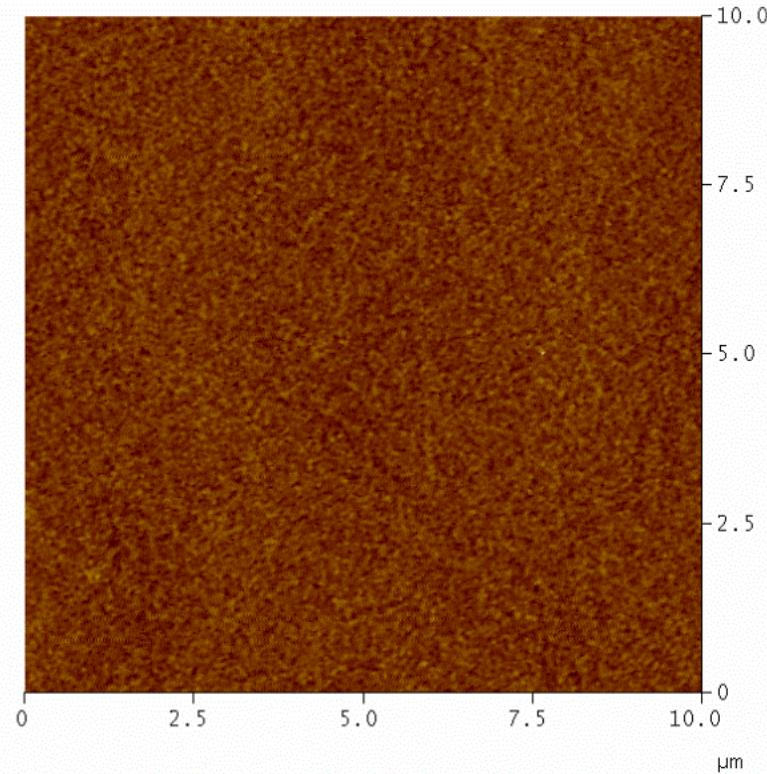


Grating for:	10.6 μm	1064 nm
Bar width	500.9 μm	49.8 μm
Groove width	499.4 μm	50.4 μm
Groove depth	2675 nm	275 nm

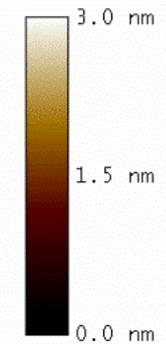
Atomic Force Microscopy of grating bar and groove



rms = 0.22 nm, F13
ox-0022-mitte-so-graben-graben_io11.100t



rms = 0.15 nm, F13
ox-0022-mitte-so-graben-steg_io11.105t

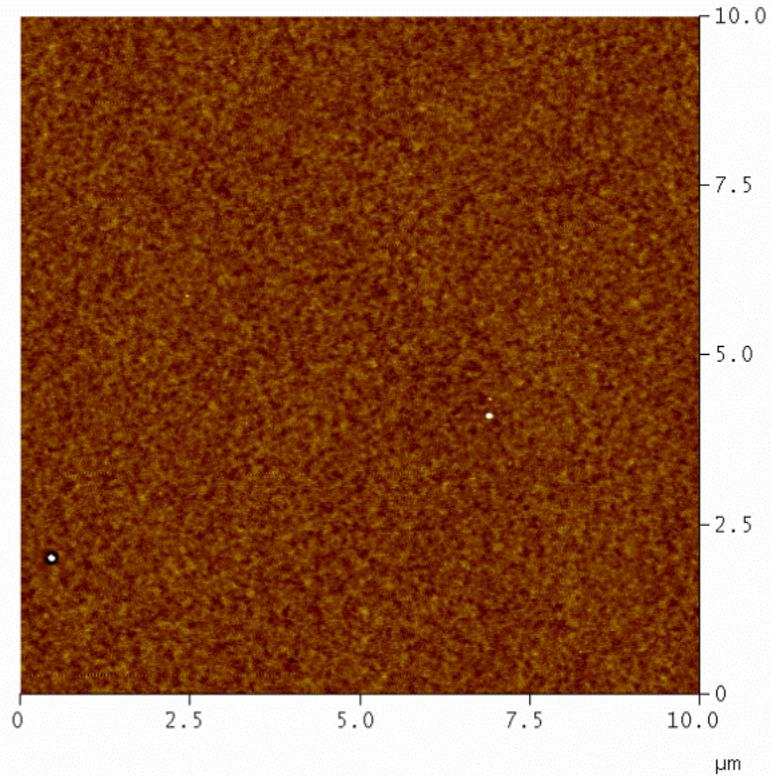


Digital Instruments NanoScope
Scan size 10.00 μm
Scan rate 1.005 Hz
Number of samples 512
Image Data Height
Data scale 3.000 nm

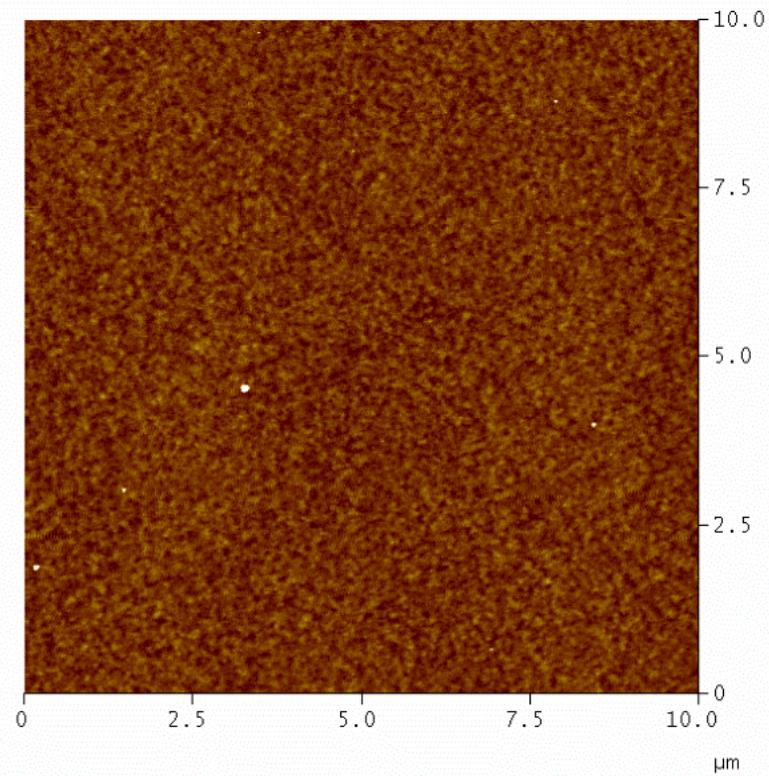
rms roughness on grating groove:
 $\sigma_{\text{RMS}} = 0.22 \text{ nm}$

rms roughness on grating groove:
 $\sigma_{\text{RMS}} = 0.15 \text{ nm}$

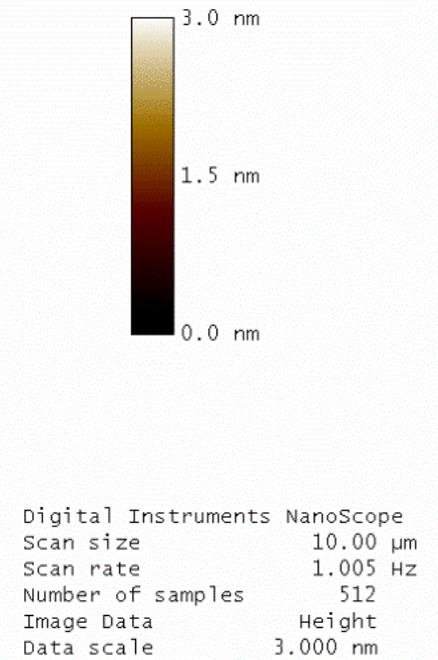
Atomic Force Microscopy of grating bar and groove



rms = 0.21 (0.19) nm, F13
ox-0022-mitte-so-steg-graben_io11.101t



rms = 0.19 (0.18) nm, F13
ox-0022-mitte-so-steg-steg_io11.104t



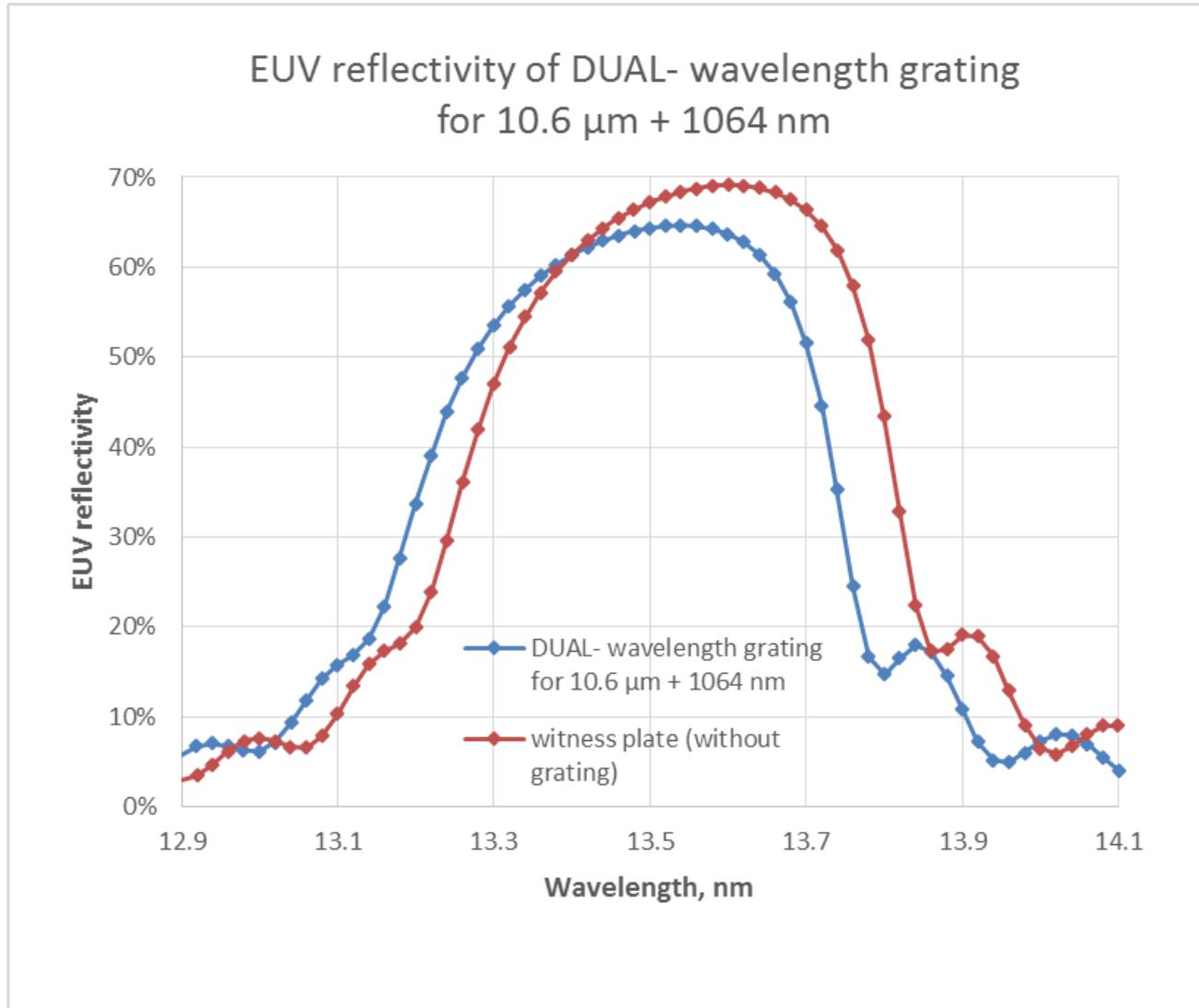
rms roughness on grating bar:

$$\sigma_{\text{RMS}} = 0.19 \text{ nm}$$

rms roughness on grating bar:

$$\sigma_{\text{RMS}} = 0.18 \text{ nm}$$

EUV reflectance measurement @ PTB Berlin



EUVR on grating structure

R = 64.6 %

$\lambda_{\text{center}} = 13.47 \text{ nm}$

EUVR on witness sample

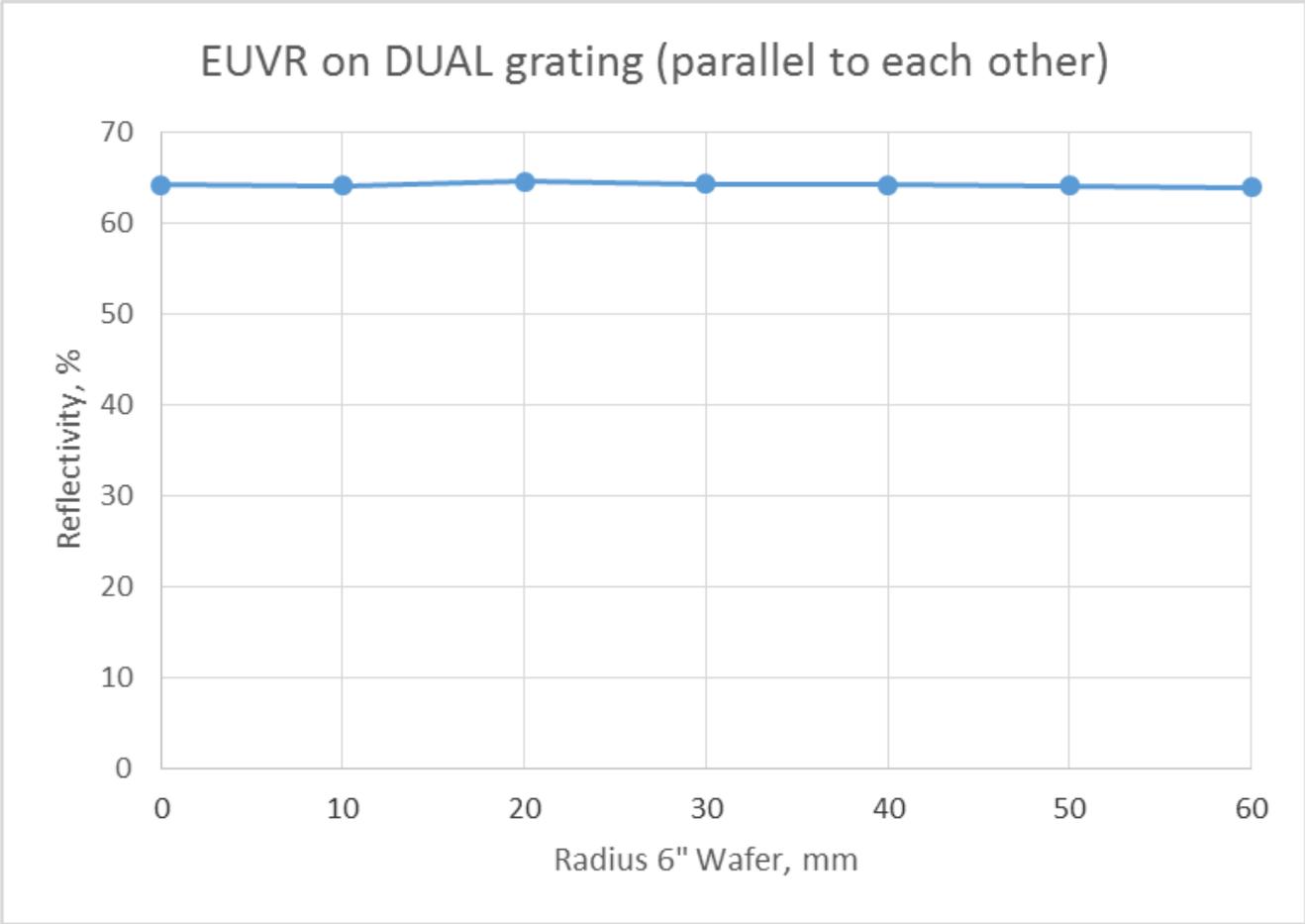
R = 69.1 %

$\lambda_{\text{center}} = 13.54 \text{ nm}$



**4.5 % (abs.) EUVR loss
due to dual-wavelength
grating structure**

EUV reflectance measurement @ PTB Berlin



EUVR on grating structure

$$R_{\max} = 64.6 \%$$

$$R_{\text{avg}} = 64.3 \%$$

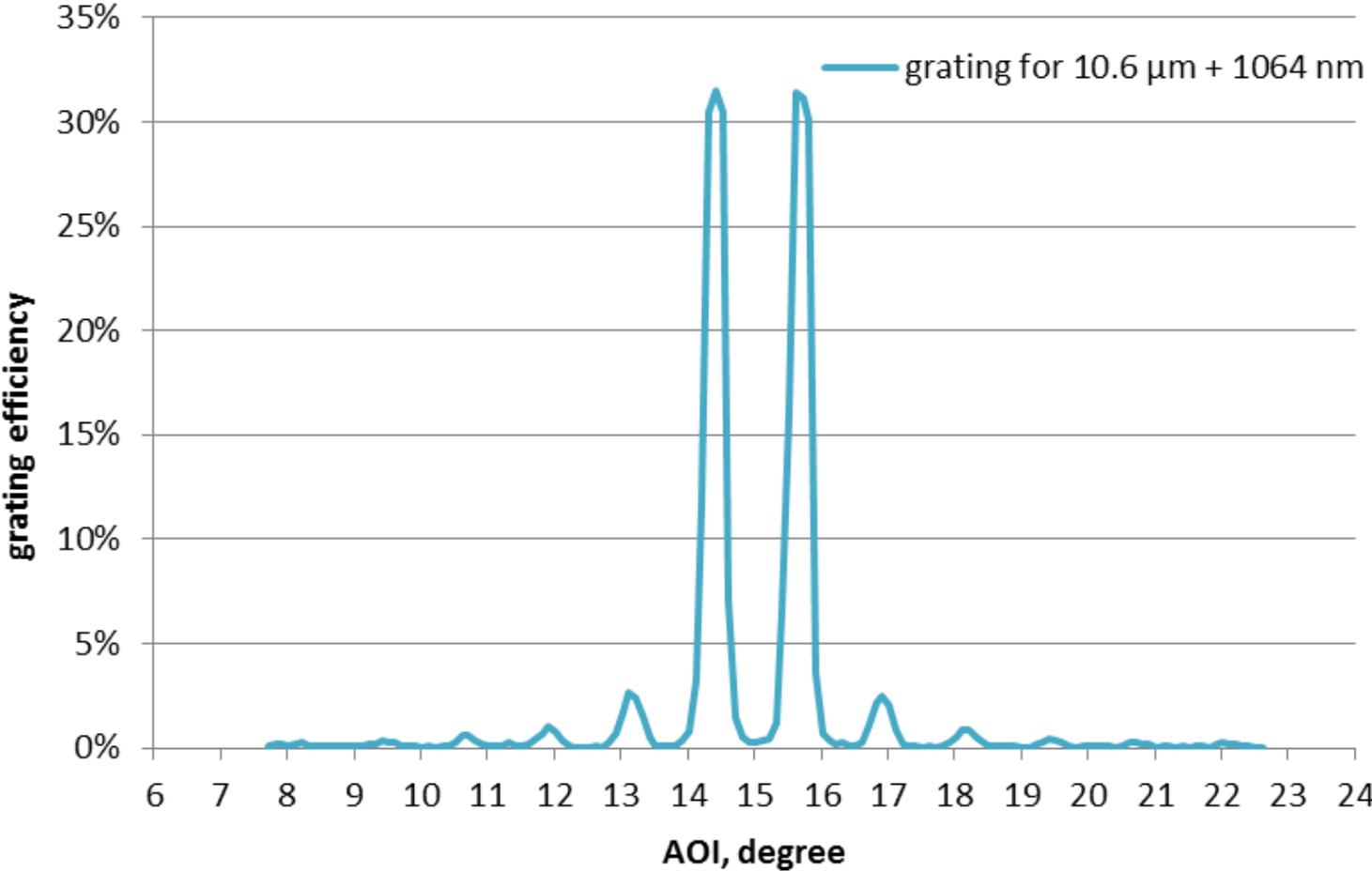
$$\lambda_{\text{center}} = (13.48 \pm 0.02) \text{ nm}$$

EUVR on witness sample

$$R = 69.1 \%$$

$$\lambda_{\text{center}} = 13.54 \text{ nm}$$

Dual grating efficiency @ 10.6 μm



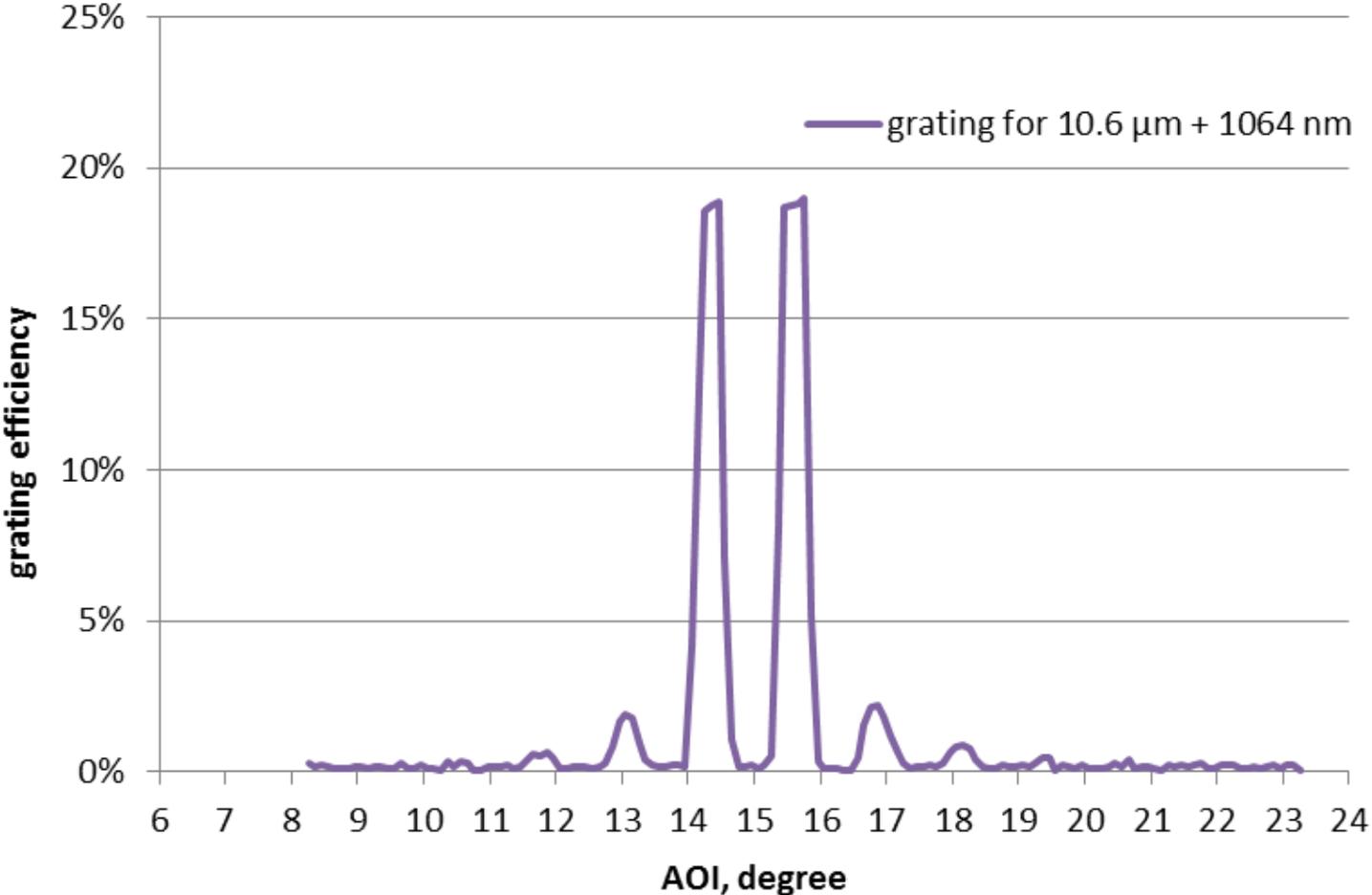
Grating efficiency @ 10.6 μm

0th order:	0.22 %
- 1st order:	31.4 %
+ 1st order:	31.4 %



IR suppression factor:
450

Dual grating efficiency @ 1064 nm



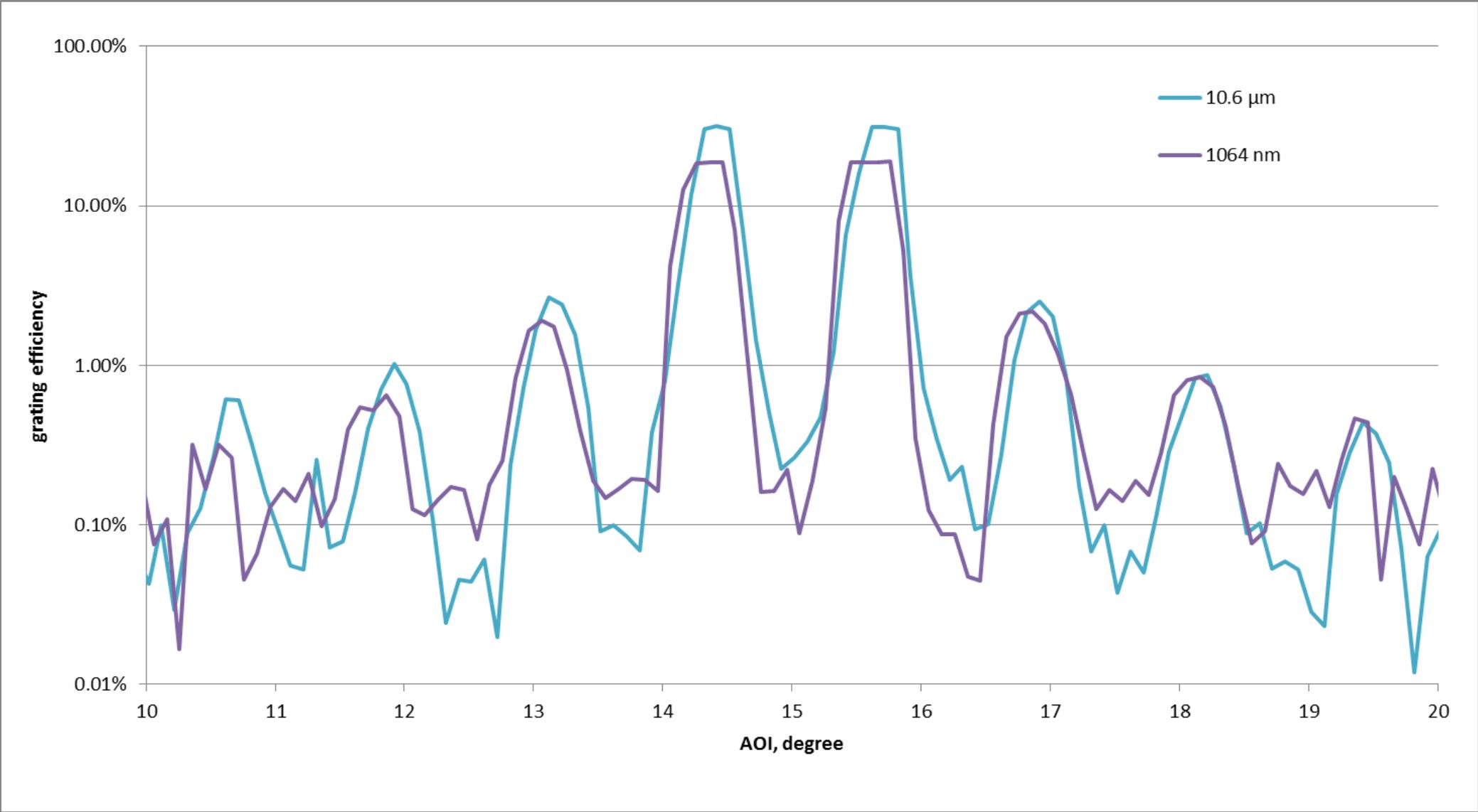
Grating efficiency @ 1064 nm

0th order:	0.22 %
- 1st order:	19.5 %
+ 1st order:	18.9 %

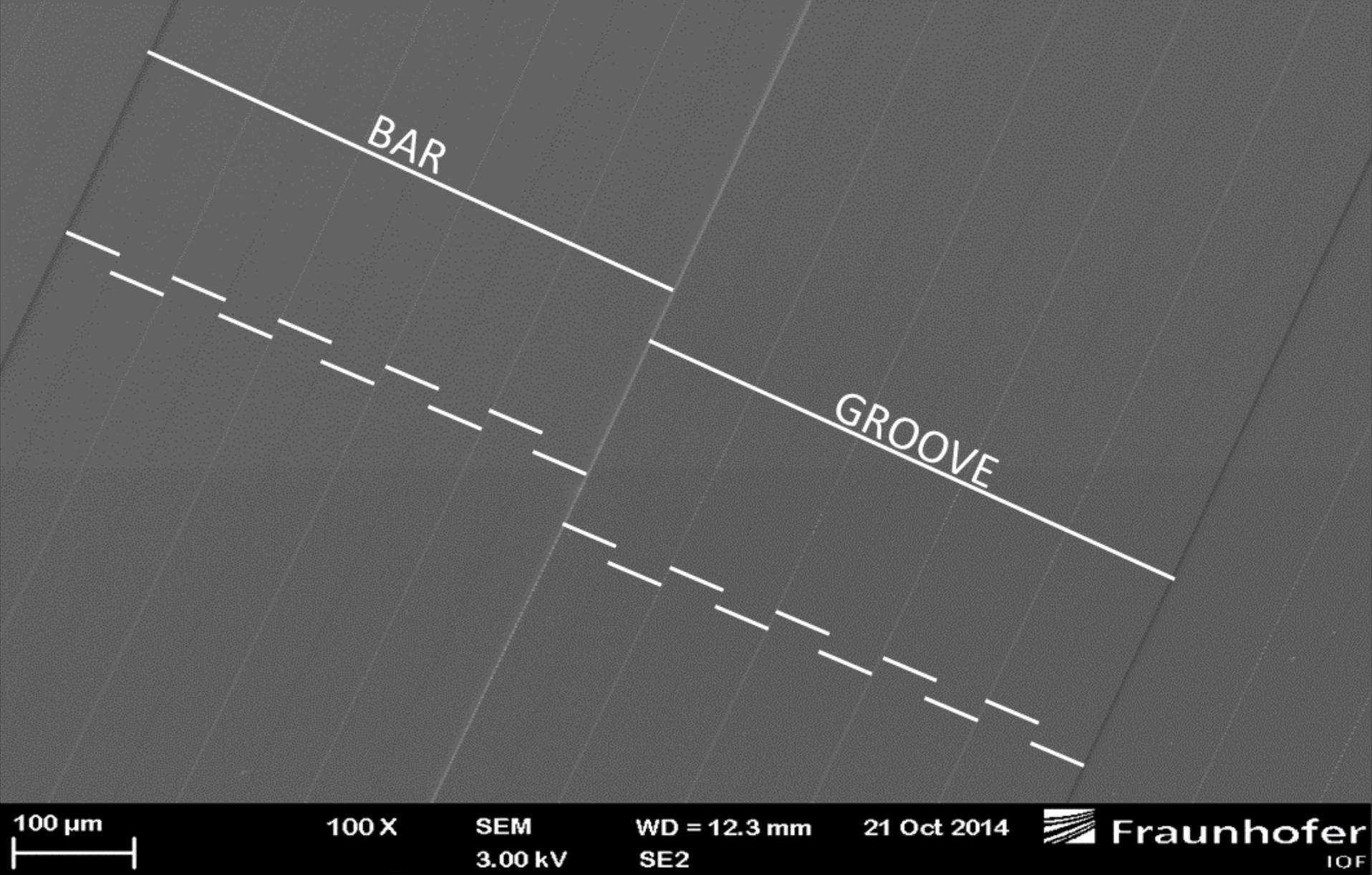


IR suppression factor:
450

Dual grating efficiency @ 10.6 μm and 1064 nm



Scanning Electron Microscopy of dual-wavelength SPF



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Summary

- Demonstration of dual-wavelength Spectral Purity Filter concept on 6" Si wafers
- EUV reflectance of 10.6 μm grating structure: **67.0 %** (2.0 % loss)
EUV reflectance of 1064 nm grating structure: **66.6 %** (2.4 % loss)
*EUV reflectance of dual-wavelength grating: **64.6 %** (4.5 % loss)*
- 0th order grating efficiency of 10.6 μm grating: **0.06 %** (1500x suppression)
0th order grating efficiency of 1064 nm grating: **0.17 %** (600x suppression)
*0th order efficiency of dual wavelength grating: **0.22 %** (450x suppression)*
*0th order efficiency of dual wavelength grating: **0.22 %** (450x suppression)*
- next step: technology extension to curved sub-aperture EUV collectors

Acknowledgements

- **EUV grating team @ Fraunhofer IOF:**

Christoph Damm, Wilko Fuhlrott, Andreas Gebhardt, Mathias Hauptvogel, Tobias Herffurth, Nils Heidler, Robert Jende, Jan Kinast, Roman Loose, Sandra Müller, Thomas Müller, Michael Scheler, Thomas Peschel, Stefan Risse, Mathias Rohde, Steffen Schulze, Ronald Schmidt, Uta Schmidt, Mark Schürmann, Ralf Steinkopf, Sergiy Yulin

- **EUV reflectivity measurement team @ PTB Berlin**

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